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It is time to integrate: The temporal dynamics of object motion and texture motion integration in multiple object tracking

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ABSTRACT

In multiple-object tracking, participants can track several moving objects among identical distractors. It has recently been shown that the human visual system uses motion information in order to keep track of targets (St. Clair et al., *Journal of Vision, 10*(4), 1–13). Texture on the surface of an object that moved in the opposite direction to the object itself impaired tracking performance. In this study, we examined the temporal interval at which texture motion and object motion is integrated in dynamic scenes. In two multiple-object tracking experiments, we manipulated the texture motion on the objects: The texture either moved in the same direction as the objects, in the opposite direction, or alternated between the same and opposite direction at varying intervals. In Experiment 1, we show that the integration of object motion and texture motion can take place at intervals as short as 100 ms. In Experiment 2, we show that there is a linear relationship between the proportion of opposite texture motion and tracking performance. We suggest that texture motion might cause shifts in perceived object locations, thus influencing tracking performance.

1. Introduction

In everyday life, humans often have to keep track of several moving objects simultaneously. For example, when playing team sports such as basketball, players have to keep track of the ball, team members, and opposing players at the same time. The visual system may use information like object identity, object position, and motion information to keep track of the objects of interest. In this study, we examine the interval at which (motion) information of multiple objects is accessed. We show that the integration of motion information can take place within intervals as short as 100 ms.

In order to perceive motion information, the human visual system samples information over more than one point in time (e.g., Lee & Lu, 2010; Lorenceau, 1996; Watamaniuk & Sekuler, 1992; for excellent overviews on this topic see Burr & Thompson, 2011; Nishida, 2011). Neurophysiological experiments showed that the upper limit of temporal integration of motion in V1 is about 100 ms (e.g., Bair & Movshon, 2004). The psychophysical approach to research on temporal integration of motion information typically uses displays depicting motion information (e.g., dots moving in random directions) for a specific duration. After having viewed a display, the participants make judgments on direction. The temporal integration interval is then estimated based on psychophysical functions such as sensitivity (i.e., the minimum stimulus duration necessary to evoke a reliable direction judgment). Depending on the kind of display (and task), the temporal integration interval ranges from 140 ms to 2–3 s. Lee and Lu (2010) have shown that quite a short interval of approximately 140 ms was sufficient to produce reliable motion judgments for multiple-aperture stimuli with multiple Gabor elements. For random-dot cinematograms with considerable directional noise, the temporal integration interval can be more than three times as long at approximately 500 ms (Watamaniuk & Sekuler, 1992). When perceiving biological motion (e.g., a walking person), motion signals are sampled over intervals as long as 3 s (Neri, Morrone, & Burr, 1998). Taken together, there is evidence that the visual system samples and integrates information over a specific temporal interval in order to estimate motion of objects.

Recently, St. Clair, Huff, and Seiffert (2010) proposed that such estimates of local motion are carried out during the visual tracking of multiple objects within the multiple-object tracking (MOT) paradigm (Pylyshyn & Storm, 1988). In a series of three experiments, the authors manipulated the motion of the objects' textures. In conditions in which texture motion and object motion contradicted each other – i.e. the texture moved in the opposite direction to the actual object – MOT performance was lower than in conditions in which the texture was either static or moved in the same direction as the object. The authors proposed that MOT relies

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on estimates of local motion (Lorenceau, 1996; Mingolla, Todd, & Norman, 1992; Morrone, Burr, & Vaina, 1995; Qian, Andersen, & Adelson, 1994; van Doorn & Koenderink, 1984; Watamaniuk & Sekuler, 1992; Weiss, Simoncelli, & Adelson, 2002; Yang & Blake, 1994), which are more accurate if object motion and texture motion do not contradict each other. However, if there is contradicting motion information (i.e., due to the texture moving in the opposite direction) this estimate of local motion becomes noisy and less accurate. Thus, they conclude that the mechanisms underlying MOT use motion information. Because texture motion was manipulated across but not within trials, no conclusions could be drawn regarding the interval length needed for effects of conflicting motion to appear.

In the present study we were interested in the interval length within which integration of object motion information and texture motion information can take place in MOT, and therefore tracking impairment caused by opposite texture motion can occur. In Experiment 1, we tested integration interval of 100 ms, 500 ms, and 2000 ms. In Experiment 2, we tested for the relationship between the proportion of opposite texture motion and tracking performance. Anticipating our results, we show that intervals as short as 100 ms are sufficient for the integration of object motion and texture motion to take place during the moment-to-moment tracking of multiple objects and that tracking performance decreases linearly with increasing proportions of opposite texture motion.

2. Experiment 1

In Experiment 1, we examined the integration of object motion and texture motion during MOT across different time intervals. In the "same" and "opposite" conditions, the texture of the spheres moved in the same or opposite direction of the sphere's movement, respectively, for the whole trial of 8 s. This corresponds to the conditions used in previous work that showed that conflicting motion information impairs multiple object tracking (St. Clair, Huff, & Seiffert, 2010). The critical new conditions in the present experiment were the "alternate" conditions, in which the texture motion alternated between "same" and "opposite" in intervals of 100 ms, 500 ms, and 2000 ms. That is, the conflicting motion information was visible for half a trial in the alternating conditions, thus causing half the number of occasions for losing a target due to conflicting motion information as compared with the "opposite" condition. Therefore, we expect the tracking performance in the alternating conditions to be between the "same" and "opposite" conditions for all interval lengths that are long enough for the integration of object motion and texture motion to occur. That is, if all our interval lengths are long enough to cause integration tracking performance should be linearly related to the proportion of opposite texture motion within a trial. If, however, any of our interval lengths are not long enough for the integration of object motion and texture motion to take place, the "opposite" motion within these intervals should not interfere with tracking, such that tracking performance should be similar in the respective alternating conditions and the "same" condition.

2.1. Method

2.1.1. Participants

Fifty-one students of the University of Tübingen participated in this Experiment. All participants had normal or corrected-to-normal vision. They received course credit.

2.1.2. Apparatus

The stimuli were presented on a notebook with a 15.4″ display with an unrestricted viewing distance of approximately 60 cm. Stimuli were presented at a resolution of 1280×1024 pixels in the center of the display and the display had a refresh rate of 60 Hz. Stimuli were generated using custom software written in Python using the 3D graphics software package Blender (www.blender.org).

2.1.3. Stimuli

We used the same stimulus material as in Experiment 3 of the study of St. Clair, Huff, and Seiffert (2010). Stimuli consisted of 3D-scenes including 12 white spheres with a wavy black line texture (Fig. 1) that moved on a gray rectangular floor depicted at a viewpoint angle of 20° in the x–y plane against a dark-blue background. The floor subtended 12.1–21.2° of visual angle horizontally and 5.7° of visual angle vertically. The spheres' diameter ranged from 0.6° to 1.0° of visual angle, depending on their location on the floor plane. The initial positions of the spheres were randomized on the floor-plane. The objects moved on linear paths and were permitted to overlap throughout the trial. The speed of the spheres was 5°/s when moving horizontally in the middle of the floor plane. Spheres bounced off the floor's edges in a physically correct way in that the sphere's direction of motion was reflected.

We realized texture motion by simulating rolling spheres. Thus, the spheres' texture motion triggered the visual impression of rolling spheres on a three-dimensional floor plane. The spheres' texture motion varied across trials and moved relative to the spheres' direction of motion at 1.74 rotations per second. The textures moved either in the same direction ("same" condition) or the opposite direction ("opposite" condition) to the ball's trajectory, or alternated from "same" to "opposite" directions in intervals of 100 ms, 500 ms, or 2000 ms, beginning with "same" direction ("alternate 100", "alternate 500", and "alternate 2000" conditions). In the alternating conditions, the spheres' texture moved in the "same" direction for 50% (4 s) of the trial and in the "opposite" direction for the remaining 50% (4 s) of the trial. Demo videos of all conditions can be viewed on the website http://www.iwm-kmrc.de/cybermedia/motion-integration/.

2.1.4. Procedure

Each trial began with the appearance of the empty floor-plane. After 2 s, 12 spheres appeared. Three spheres were designated as targets by flashing red four times over the course of 1.6 s and then remaining red for a further 2 s. After the targets turned white again, all of the spheres moved on linear paths but in randomly selected directions for 8 s. At the end of the trial, the spheres remained stationary while participants used the mouse to select the supposed targets. After each selection, the selected sphere turned red. After each trial, participants received feedback about their tracking performance (e.g., "2 out of 3 correct"). Participants pressed the space

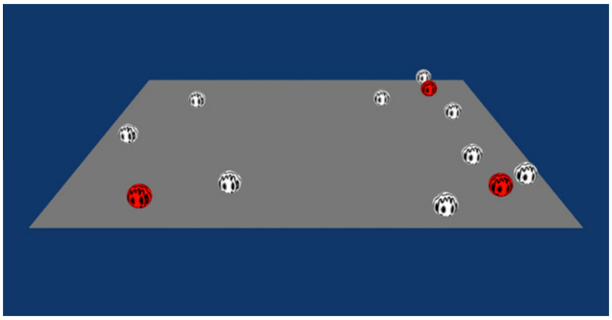

Fig. 1. Example of the 3D scenes during the target designation period. Red spheres indicate targets. During the subsequent tracking period, all spheres were white with a wavy black line texture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)